MBSE approach to support and formalize mission alternatives generation and selection processes for hypersonic and suborbital transportation systems

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***Abstract*—This paper deals with the application of a Model Based Systems Engineering (MBSE) approach to support and formalize mission alternatives generation and selection processes aimed at developing operative hypersonic and suborbital transportation systems. Due to the high-level of complexity of these ultimate aerospace initiatives, a MBSE approach demonstrates to be very effective to allow reduction of risk of inconsistencies, of unappropriated or incompatible design choices, reducing the overall time and effort spent in design and development phases. After a brief introductory section aimed at providing some details about these kinds of vehicles, both in terms of enabling technologies and missions, a step-by-step innovative methodology based on a MBSE approach to carry out mission analysis is proposed. All along the methodology description, the application to a specific reference case study of a suborbital single-stage vehicle aimed at performing commercial parabolic flight services is proposed. Eventually, the selected mission baseline is detailed and the major benefits and further application of this innovative integrated methodology are reported and discussed.**

Keywords—Mission Analysis, Model Based Systems Engineering (MBSE), hypersonic, suborbital transportation system.

I. Introduction

The aeronautical and the aerospace engineering domains are clear examples of technological fields with a current increasing speed of technical development. Indeed, in the last decades, the aeronautical and aerospace engineering fields have been affected by the so-called phenomenon of convergence of interests, mainly in terms of altitude. This trend can be justified considering that aeronautics has a great interest in developing faster transportation systems, increasing the terrestrial net of connections. To reach this goal, flight altitude should increase, moving cruise legs to those regions of the atmosphere that were typically considered part of the space domain. On the other hand, the development of innovative technologies can allow space engineers to overcome problems faced when they are approaching these high atmospheric layers during re-entry. These innovative vehicles will be characterized by a very high level of complexity that forces the designers to find innovative design methodologies aimed at reducing the risk associated to wrong high level design choices and allowing money and time saving. In this context, this paper suggests an innovative methodology based on a Model Based Systems Engineering (MBSE) [1] [2] approach to support Mission Analysis activities, i.e. all those complex design activities aimed at providing the engineers with the mission baseline as starting point for vehicle design, beginning with stakeholders' needs and high level strategic decisions analyses.

With the goal of proving the readers with a common understanding on the major issues related to hypersonic initiatives, Section II gives a qualitative overview of hypersonic transportation systems and missions, highlighting the major technological and operational challenges. At the end of Section II, the case study exploited all along the paper is also introduced. Then, Section III is entirely devoted to the description of the suggested integrated methodology based on a MBSE approach. The methodology is presented following a step-by-step approach, and for each group of activities, the model implementation of the selected reference case study is reported. Section IV summarizes the major results obtained from the application of the proposed integrated methodology to the reference case study, while Section V provides additional suggestions to extend its application to the following design stages or to other case studies.

II. Hypersonic and Suborbital transportation Systems

A. Background

Accepting the definition of Kenneth Chang, October the 20th, 2014 on the eminent New York Times [3] spaceplanes are so fascinating because they are aerospace vehicles able to operate as aircraft when they are in the lower atmospheric layers and as spacecraft when they are in space. From one side, this definition is essential to understand the reasons of such increasing interest in these vehicles by both the aeronautical and space domains, but on the technological point of view, it reveals the level of complexity of such a transportation system.

The need to go higher and faster forces the engineers and scientists to find new technological solutions in order to overcome some limits and to comply with even more strict and demanding sets of mission requirements. In particular, the major fields of research in the domain of hypersonic vehicles are:

- Aerodynamics and aerothermodynamics
- Structural optimization
- High speed air-breathing propulsion
- Mission Trajectory

However, multidisciplinary aspects such as the eco-compatibility, regulatory framework, spaceport and safety should be properly taken into account and investigated. Furthermore, it is convenient to notice that one of the major responsible of the high level of complexity characterizing both hypersonic vehicles and related missions is the required integration of these innovative technologies, in new fashions, often combining low TRL (Technology Readiness Level) technologies attempting reaching the highest possible SRL (System Readiness Level), maximizing the IRL (Integration Readiness Level).

Considering all the past and currently under-development projects, it is very difficult to find a unique parameter for the classification of vehicles dealing with hypersonic. Indeed, depending on the specific discipline, they can be grouped following different criteria. The easiest categorizations are based on the operative environment [4] or on the maximum achievable Mach number. However, an interesting classification criterion has been proposed by Hirschel in several works [5][6] and also used by other authors [7] [8]. This hybrid categorization mixes together configurational characteristics, propulsive strategy and mission profiles. In order to include suborbital vehicles within this classification, the following categorization is adopted:

- Re-entry Vehicles (RV)
  - Winged re-entry vehicles (W-RV)
  - Non winged re-entry vehicles (NW-RV)
- Ascent and re-entry vehicles (ARV)
  - Orbital ascent and re-entry vehicles (O-ARV)
  - Suborbital ascent and re-entry vehicles (SO-ARV)
- Cruise and acceleration vehicles with air-breathing propulsion (CAV)

B. *Reference Case Study*

In this paper, the methodology based on a MBSE approach is applied to the Mission Analysis of a real initiative, led by Altec. S.p.A with the support of Politecnico di Torino (which the authors belong to) and Thales Alenia Space Italy – Turin [9] [10] [11], aims at exploiting a pre-feasibility study for a group of Malaysian private stakeholders. The initiative aimed at providing regular parabolic flight services to reach 100 km of altitude allowing passengers to experience a short period of microgravity and an amazing view of the Earth.

III. INNOVATIVE MISSION ANALYSIS METHODOLOGY BASED ON A MBSE APPROACH

This section aims at suggesting a MBSE approach to support the mission analysis activities in the aerospace field, showing as reference test-case the suborbital flight domain. This section is organized in two main subsections each of which aimed at providing a theoretical description of a methodology step, MBSE implementation details and application to the reference case-study, following the activity-flows reported in Figure 1.

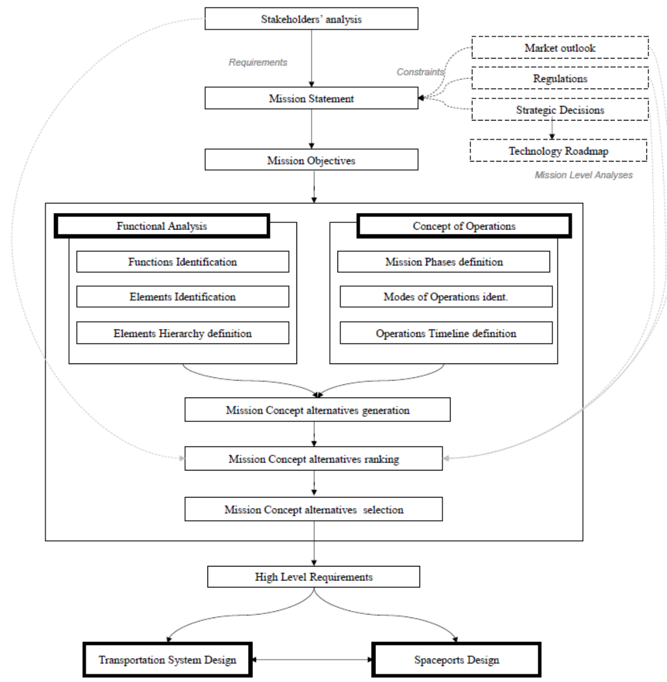

Figure 1: Flowchart of the activities involved within the proposed approach

A. *From High-Level Mission Analysis to the mission concepts alternative generations*

The overall design process is intended to start with the identification of the Stakeholders, i.e. all those people that could be interested in the project. In order to pursue a well-organized stakeholder analysis, it is important to understand the role that each identified stakeholder could play in the specific mission. Then, it is necessary to gather information about their needs, trying discovering their hidden desires. Following the NASA guidelines for classification [12], stakeholders could be classified depending on their role and interest in the project, as follows:

- Sponsors: private or public associations who establish a mission statement and fix boundaries on both the schedule and funds availability.
- Operators: all those people, usually belonging to engineering associations, in charge of controlling and maintaining both space and ground assets.

- End-users: all those people that will receive benefits from the mission operations and will use space mission's products or capabilities. Usually they belong to the scientific or engineering community.
- Customers: they differ from the previous category, because they are users who pays fees to exploit specific products or services offered by the mission.

Moreover, as highlighted in Figure 1, besides representing the major activities of this preliminary phase, the stakeholders analysis must be supported by secondary investigations aimed at verifying the possibility of the current market to accommodate this under-development product or service and the presence of specific regulations, precious source or requirements, but also constraints. In addition, it is very important to be aware of the current strategic decisions that might have a noticeable impact on the possibility of development of these initiatives.

The results of the in-depth analyses of the stakeholders and related needs as well as of the current aerospace market, considering possible limitations imposed by the under-development regulatory framework and the high level strategic decision, allows deriving the Mission Statement and generating a first list of Mission Objectives. They constitute the starting point for the elicitation of a first list of requirements, usually referred to as mission requirements. It is convenient to notice that, in case strategic decisions are present, programmatic requirements can be generated too.

As far as the reference case study is concerned, the following mission statement and related list of primary and secondary mission objectives have been derived.

Mission Statement:

"The mission shall allow regular flight services to enable 4 flight participants at a time to reach 100 km to experience a period of microgravity and an amazing view of the Earth. The spacecraft shall perform a vertical take-off from a sea-based or land-based platform and a vertical landing on the same site. Moreover, the additional capability to perform an un-crewed mission shall be considered"

Primary Objective:

- To allow regular suborbital parabolic flights service

Secondary Objectives:

- To demonstrate the Malaysian capabilities to develop, produce and operate suborbital vehicles.
- To demonstrate the Malaysian capabilities to support regular spaceflight activities.
- To demonstrate the possibility of performing parabolic flight with fully reusable transportation systems.
- To enhance the public consensus in commercial flight activities (i.e increasing the interest of non-experts in this kind of disruptive innovative technologies)
- To enhance key-technologies' Technology Readiness Levels (TRLs).

In a MBSE perspective, exploiting SysML standards [13], this first step can be formalized by means of a Use Case Diagram (UCD) (see Figure 2). It can be seen as a graphical representation of a user's interaction with the system that shows the relationship between the users/actors (in this case the stakeholders) and the different use-cases (Mission Objectives) in which the actors are involved. The exploitation of a proper layout allows representing and communicating the type of relationships existing among the elements of the diagram. In particular, in order to express the stakeholder categorizations, generalization links have been used, while to express the interest of each single stakeholder in one or more mission objectives, the association link is suggested. It is also possible noticing that the links allow defining hierarchical relationships between elements; e.g. the secondary objectives are related to the primary one by means of dependency links, with a specific stereotype ("include"). Another major outcome of this high level analysis, as mentioned before, is the generation of a first list of mission and programmatic requirements. As well as all the other requirements, which will be generated all along the product life cycle, they can be written in a proper database, allowing their storage and management. The exploitation of a model-based approach allows not only to simply write and record statements but also to specify attributes, to classify them, to establish mutual relationships (internal traceability) but also to connect these requirements to other elements of the model (external traceability). These links are not only formalisms but they are essential to trace the various design choices as well as to verify the satisfaction of requirements by the models elements. Once the main objectives of the mission under investigation have been clarified, the developers should elaborate different ideas to accomplish this mission in the optimal way.

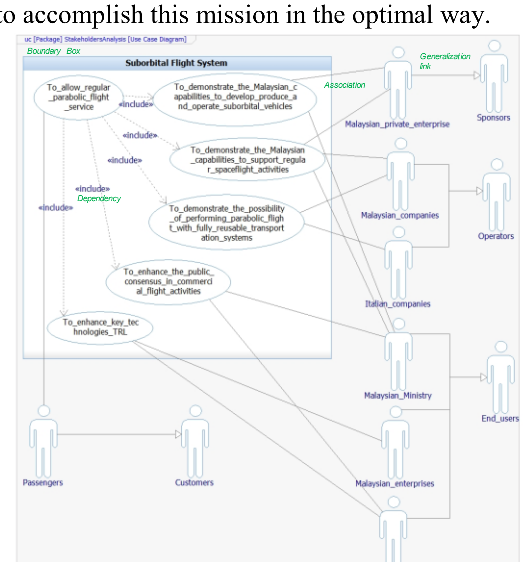

Figure 2: UCD formalizing the stakeholders analysis

This can be done following these steps:

1. Identification of the functionalities required to accomplish the already defined mission objectives. This can be carried out exploiting a traditional functional tree that can be formalized by means of a Block Definition Diagram (BDD) following the MBSE approach (Figure 3). In addition, the first list of

functional requirements can be elicited. However, from the grammatical point of view, the subject of these statements cannot be specified, but ore generic nouns shall be exploited. From the end of the next step, a revision process of these requirements will be performed allowing better specifying them depending on the proposed allocation of functions to products. Please notice that the exploitation of Requirements Management tools guarantees to trace all these changes, allowing the engineers, at any time, to verify the evolution of each single requirement.

2. Identification of all the possible products able to perform each single function previously identified. This analysis can be supported by the exploitation of function/product matrix, in a non-orthodox way. Indeed, the usual procedure prescribes that each identified product can be able to perform more than one function, but each function shall be carried out by a single product only. This guarantees an optimization of the resources and allows preventing the user to mix together different hierarchical levels. However, in this context, a non-orthodox exploitation of this tool is suggested, proposing the users to identify and list all the possible elements able to perform each single function. This will result in a matrix with a higher number of valid intersections.
3. Before moving to a pure physical view, it is necessary to assemble mission scenarios through proper combination of one alternative per function. This is quite a tricky process but it allows to enlarge the design space, i.e. the number of possible mission concept alternatives, increasing the number of combination. In this way, a hypothetical mission concept consists in the integration of one alternative per each element. Of course, it is clear that proper feasibility studies should support this process, in order to immediately neglect unfeasible or not viable combinations. In this context, the exploitation of the Quality Functional Deployment (QFD) tool is suggested. Besides the fact that this tool is not one of the traditional tools of the Systems Engineering, the here proposed exploitation of QFD tool can be suggested as additional tool of a MBSE approach. Notwithstanding, the presented application to the reference case-study will demonstrate that it is possible to fully integrate QFD in MBSE tool chain. The QFD will be exploited within an iterative and recursive process allowing not only the generation of mission scenarios alternatives but also their prioritization on the basis of proper criteria, directly coming from the stakeholder analysis.
4. The most promising scenarios, whose number depends on the possibility to carry on parallel analyses for more alternatives, can be furtherly detailed from both a physical and a behavioural standpoint. As far as the physical description is concerned, product tree can be exploited. This is another activity that can be formalized by means of a BDD in SysML.

The product tree (see Figure 4) is here conceived in order to have three hierarchical levels, being consistent with the level of detail expressed in the functional tree. The suborbital flight System of Systems is the main assembly, whilst three segment-level products have been identified, each of which may be composed by other systems. Requirements definition and classifications follow this breakdown too.

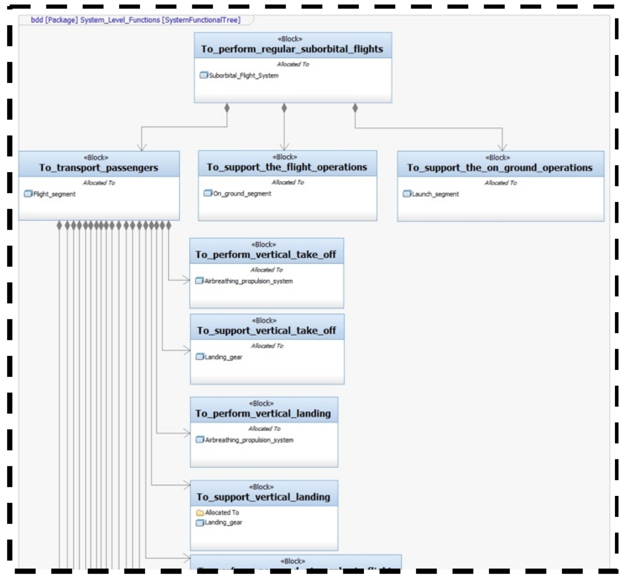

Figure 3: Detail of the functional tree implemented through the BDD

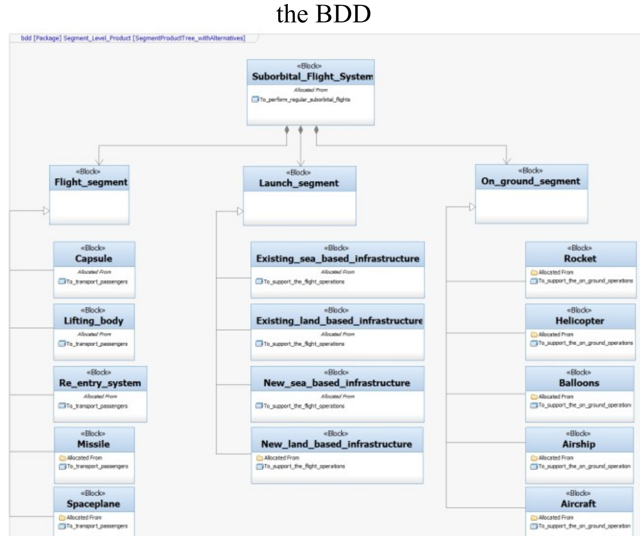

Figure 4: Product tree implemented through the BDD

B. *Mission Baseline Selection and Requirements management*

At this point, it is important to group and combine the elements to derive the different mission concept options. During this process it is fundamental to evaluate how well each of the different options derived for each single function is able to accomplish the function itself and which is its relation

to all the other functions of the mission. In order to increase the level of autonomy of the process, a Quality Functional Deployment (QFD) tool, also known as House of Quality (Figure 5), can be considerably helpful. In the following figures, the application of the QFDs to the case study is reported. They have been obtained implementing the mathematical algorithms on Excel sheets, obtaining a simple but very useful and reusable ad-hoc built-in tool.
In this context, due to the limited number of pages, the rational used to assign weights and evaluations, as well as the selection of the figures of merits is not detailed, but in [9] the reader can find the mathematical algorithms behind each step. However, it is fundamental noticing that among the selected figures of merits, the safety has been taken in special consideration, following the needs of the stakeholder, whose major purpose was to enhance the public consensus. This will allow to properly prioritize the mission alternatives.

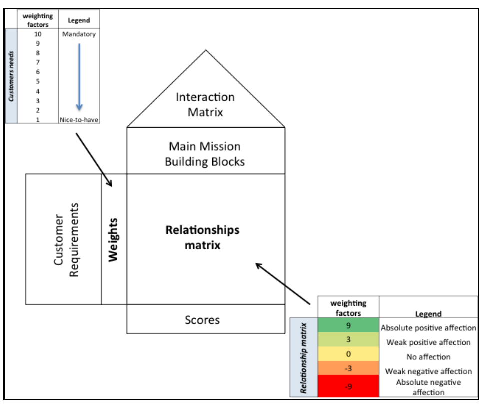

Figure 5: Structure of the QFD for alternative generation

From the mathematical standpoint, once a scoring criterion has been fixed, it is possible to rank the elements inserted in the columns of the first QFD (an example is reported in Figure 6), at segment level. This is obtained applying the following equation:

$$S_{BB_j} = \sum_{i=1}^{n_{req}} \left[\left(w_{req}\right)_i \cdot \left(w_{rel}\right)_{ij} \right]$$

where:

i is the requirements index;
j is the Building Blocks index;
S_{BB_j} represents the score related to the j-th Building Block;
$\left(w_{req}\right)_i$ is the weighting factor assigned to the i-th requirement.
$(w_{rel})_{ij}$ is the weighting factor assigned within the relation matrix.

			Ground Segment Areas of influence			Flight Segment Areas of influence			Launch Segment areas of influence				
	Weighting Factors	Normalized Weighting factors	Infrastructure	Safety	Trajectory	Staging strategy	Payload capability	Reusability	Lauyout configuration	On-board Systems	Vehicle performances	Need Priority	Normalized Need Priority
Customer needs													
Suborbital mission profile	10	0,108	9	0	9	9	3	0	0	9	9	480	55,81
100 km target altitude	10	0,108	3	0	9	9	9	0	0	9	9	480	56,45
120 sec microgravity	8	0,086	0	0	9	3	9	0	3	9	9	336	32,52
Proper view of the Earth	6	0,065	0	0	3	0	0	0	3	3	0	54	4,065
Safe escape system	10	0,108	0	9	3	9	0	0	9	9	0	390	46,13
Easy Boarding	5	0,054	0	3	0	0	0	0	9	3	3	90	5,806
Accomodation for 4 flight participants	10	0,108	0	0	0	0	9	0	9	9	0	270	31,94
VTOL	10	0,108	3	9	9	3	0	0	3	9	9	450	52,9
Landing at the take-off location	10	0,108	9	9	9	0	0	0	9	9	9	540	62,9
Short time-to-market	7	0,075	-3	-3	0	0	3	-3	-3	-3	0	-84	-7
Routine services	7	0,075	9	3	0	-9	0	9	0	3	9	168	13,77
Design specification priority			282	285	480	261	303	42	366	645	510		
Design specification priority (normalized)			3,0323	3,065	5,1613	2,806	3,258	0,5	3,935	6,935	5,484		

Figure 6: QFD at segment level

Then, a second QFD matrix (examples is reported in Figures 7, 8 and 9) could be used in order to prioritize the mission elements options. Indeed, each building block has to be considered as a collection of interconnected elements. At top level, it is important to consider all the possible options for the elements of a mission. To this purpose, the methodology has been applied to prioritize the mission elements. In order to perform this activity in a logical and structured way, the authors propose to build several QFDs, one per each original function of the Functional Tree and use a combination algorithm later on, in order to generate the different mission concept options.
Applying the same above-described methodology, the mission elements prioritization could be obtained applying the following equation:

$$(S_{EO})_{lm} = \sum_{i=1}^{n_{req}} \left[\left(w_{req}\right)_i \cdot (w_{rel})_{il} \right]$$

where:

i is the requirements index;
l is the element options index;
$(S_{EO})_{lm}$ represents the score related to the l-th element option able to accomplish the m-th mission function;
$\left(w_{req}\right)_i$ is the weighting factor assigned to the i-th requirement.
$(w_{rel})_{il}$ is the weighting factor assigned within the relation matrix

The values obtained could be used to prioritize the options for each element. If the process is carried out for each function that the mission shall perform, the engineers can have several rankings, one for each function. The following step implies the combination of the elements in order to create mission concept options. This activity can be automatically performed making all the existing combinations, sorting one element per list.
Remembering that each element has been previously scored, the score related to each derived mission concept is a linear combination of the scores obtained in the previous steps, as stated by the following equation:

$$(MC)_k = \sum_{p=1}^{n_{ele}} \left[(S_{EO})_p \right]$$

where:

k is the mission concept index;
p is the element options index;
$(S_{EO})_p$ represents the score related to the l-th element option able to accomplish the m-th mission function;

The number of possible combination will be exactly foreseen since the beginning using the following equation:

$$n_{MC} = \prod_{q=1}^{n_{fun}} (n_{eo})_q$$

where

n_{MC} is the maximum number of mission concept options;
n_{eo} is the overall number of element options;
n_{fun} is the number of functions (i.e. the groups from which element options should be taken).

		Weighting factors	*Normalized Weighting factors*	***Ground Segment Alternatives*** *Existing sea-based Infrastructure*	*Existing land-based Infrastructure*	*New sea-based Infrastructure*	*New land-based Infrastructure*	**Impact Area Priority**	**Normalized Impact Area Priority**
Ground Segment Areas of influence	Infrastructure	282	3,032	3	3	-3	-3	0	0,0
	Safety	285	3,065	9	-3	9	-3	3420	36,8
	Trajectory	480	5,161	3	3	3	3	5760	61,9
Launch Segment Areas of influence	Staging strategy	261	2,806	0	0	0	0	0	0,0
	Payload capability	303	3,258	0	0	0	0	0	0,0
	Reusability	42	0,452	0	0	0	0	0	0,0
Flight Segment Areas of influence	Lauyout configuration	366	3,935	-3	-3	0	0	-2196	-23,6
	On-board Systems	645	6,935	-3	-3	0	0	-3870	-41,6
	Vehicle performances	510	5,484	-3	-3	3	3	0	0,0
	Design specification priority			288,0	-3132,0	4689,0	1269,0		
	Design specification priority (normalized)			3,1	-33,7	50,4	13,6		

Figure 7: QFD for systems belonging to Ground Segment

		Weighting factors	*Normalized Weighting factors*	***Flight Segment Alternatives*** *Capsule*	*Lifting Body*	*Re-entry System*	*Missile*	*Spaceplane*	**Impact Area Priority**	**Normalized Impact Area Priority**
Ground Segment Areas of influence	Infrastructure	282	3,032	-9	-9	-9	3	9	-4230	-45,48
	Safety	285	3,065	-3	3	3	3	9	4275	45,97
	Trajectory	480	5,161	3	3	3	3	3	7200	77,42
Launch Segment Areas of influence	Staging strategy	261	2,806	3	3	3	3	9	5481	58,94
	Payload capability	303	3,258	-3	3	3	9	9	6363	68,42
	Reusability	42	0,452	-9	3	-3	-9	9	-378	-4,065
Flight Segment Areas of influence	Lauyout configuration	366	3,935	0	3	3	3	9	6588	70,84
	On-board Systems	645	6,935	-9	-3	-3	3	9	-1935	-20,81
	Vehicle performances	510	5,484	-9	-3	3	6	9	3060	32,9
	Design specification priority			-12852	-792	2016	12366	25686		
	Design specification priority (normalized)			-138,2	-8,52	21,7	133	276,2		

Figure 8: QFD for systems belonging to Flight Segment

				Launch Segment Alternatives							
		Weighting factors	Normalized Weighting factors	None	Rocket	Helicopter	Balloons	Airship	Aircraft	Impact Area Priority	Normalized Impact Area Priority
Ground Segment Areas of influence	Infrastructure	282	3,03	9	-9	3	3	3	3	3384	36,4
	Safety	285	3,06	9	-9	-3	-3	-3	3	-1710	-18,4
	Trajectory	480	5,16	0	0	-3	-3	-3	-3	-5760	-61,9
Launch Segment Areas of influence	Staging strategy	261	2,81	0	9	3	3	3	9	7047	75,8
	Payload capability	303	3,26	-9	-3	-9	-3	-3	3	-7272	-78,2
	Reusability	42	0,45	9	-3	3	3	3	9	1008	10,8
Flight Segment Areas of influence	Lauyout configuration	366	3,94	0	0	-3	-3	-3	-9	-6588	-70,8
	On-board Systems	645	6,94	0	0	0	0	0	0	0	0,0
	Vehicle performances	510	5,48	9	3	-3	-3	-3	9	6120	65,8
	Design specification priority			7710	-1893	-4434	-2616	-2616	8844		
	Design specification priority (normalized)			79,0	-24,3	-63,4	-43,8	-43,8	55,8		

Figure 9: QFD belonging to Launch Segment

Once the mission baseline has been selected, a new set of requirements shall be elicited. In particular, it is possible to review the high level requirements, especially the functional ones, better specifying the grammatical subject of each requirement. For example, a high level requirement elicited after a first iteration can be written in the form "The system should be able to support the vehicle during take-off and landing operations", while the same requirement can be re-written as follows "The Landing Gear shall support the vehicle during take-off and landing operations". The specific name of the system can only be introduced after function device matrix has been completed. This is a fundamental activity that will allow starting a new level of design process. The whole requirements specification is reported in Figures 10, 11 and 12 respectively for Mission, Programmatic and Functional requirements, as it appears within the requirements management system. Figure 13 shows the updating process after the system level allocation.

ID	
MR1	The mission shall allow regular parabolic suborbital flight service.
MR2	The mission shall allow to 4 passengers at a time to experience at least 2 minutes of microgravity.
MR3	The mission shall allow the passengers to reach a flight altitude of at least 100 km.
MR4	The mission shall allow the passengers to appreciate the Earth curvature.
MR5	The mission shall enable the flight service to be carried out from both land-based or sea-based platforms.
MR6	The mission shall be conceived in order to guarantee the coincidence of departures and landing sites.

Figure 10: Mission Requirements

ID	
PR1	The mission shall be carried-out on the Malaysian territory.
PR2	The maiden flight shall be performed by the end of 2020.
PR3	The mission shall rely as much as possible on high TRL technologies.
PR4	The mission shall increase the Malaysian role in spaceflight.

Figure 11: Programmatic Requirements

ID	
FR1	**1 Top Level Requirement**
FR2	The Suborbital Flight System shall be able to perform regular suborbital flights.
FR3	**2 Segment Level Requirements**
FR4	The Flight Segment shall be able to transport passengers during the envisaged mission.
FR5	The Ground Segment shall be able to support the operation of the transportation system during its flight.
FR6	The Launch Segment shall be able to support the transportation system when on ground.
FR7	**3 System Level Requirements**
FR8	The air-breathing propulsion system shall be able to perform vertical take-off (or lift-off).
FR9	The landing gear shall be able to support the transportation system during vertical take-off (or lift-off).
FR10	The air-breathing propulsion system shall be able to perform vertical landing.
FR11	The landing gear shall be able to support the transportation system during vertical landing.
FR12	The air-breathing propulsion system shall power the aircraft during flight phases carried out in atmospheric environment.
FR13	The rocket propulsion system shall power the aircraft during flight phases carried out in space environment.
FR14	The Flight Control System (FCS) shall allow controlling the transportation system during flight phases carried out in atmospheric environment.
FR15	The Reaction Control System (RCS) shall allow controlling the transportation system during flight phases carried out in space environment.
FR16	The Thermal Protection and Control System (TPCS) shall be able to sustain thermal loads.
FR17	The airframe shall be able to sustain structural loads.
FR18	The air-breathing propulsion system shall be able to perform a cruise back allowing the transportation system to land on the same site from which it took off.
FR19	The crew compartment shall allow to properly accomodate the crew.
FR20	The passenger compartment shall allow to safely accomodate non trained passengers guaranteeing a proper level of comfort during the overall mission profile.
FR21	The Environmental Control and Life Support System (ECLSS) shall guarantee crew and passengers survaivability.
FR22	The avionic system shall allow communications during the overall mission profile.
FR23	The avionic system shall support the required guidance and navigation functionalities.
FR24	The Environmental Control and Life Support System (ECLSS) shall guarantee crew and passengers survivability in case of emergency.
FR25	The Electrical Power System (EPS) shall provide electrical power during the overall mission profile.
FR26	The Cabin Escape System (CES) shall allow safe escape during specific mission phases.

Figure 12: Functional Requirements

Generale | Accesso | Cronologia | Attributi | Link | Discussioni

Utente	Sessione	Data	Modifica
Administrator	7	19/05/2017 16:14:29	Modifica attributo dell'oggetto: Object Text

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The ~~System~~air-breathing propulsion system shall be able to perform vertical take-off (or lift-off).

Figure 13: Example of updating process for FR008

IV. Results

The approach described in Section III allows selecting the most suitable baseline up to system level. As it is possible to notice from the different QFDs, the winner baseline is represented by a mission carried out by a single stage vehicle able to perform all the mission phases starting from an ad-hoc developed sea-based spaceport infrastructure. The launch segment is then not required.

The application of the MBSE process results very helpful in allowing a formalized generation and selection of mission alternatives, during the high level design phase, since it guarantees the complete traceability of elements among different tools, peculiar of Systems Engineering, through the enhanced features proposed by the exploitation of software platforms. The high level of complexity characterizing the system of interest brings a noticeable amount of information to be processed and a considerable set of topics and parameters to be considered. Without a model-based approach, the analysis would have been problematic and the risk associated to the loss of data or to the identification of an improper baseline could arise. The adoption of such approach is then suggested particularly at the beginning of the design process, when the product is still not existing while the influence on its final configuration is relevant.

V. Conclusion

This paper shows the application of a Model Based Systems Engineering (MBSE) approach to support and formalize mission alternatives generation and selection processes aimed at developing operative hypersonic and suborbital transportation systems. It allows selecting the most suitable baseline for a suborbital vehicle aimed at performing commercial parabolic flights. The integrated methodology suggested appears of absolute relevance in the field mission and space vehicle design, especially in conceptual design phases. The application of the same approach for the system and subsystem design levels is currently under-evaluation with promising results. The outcomes of these investigations should confirm that one of the most relevant innovation introduced with the presented methodology is the possibility of guaranteeing an adequate level of repeatibility. Of course, this aspect will be benefical for the overall reasearch and development time and costs.

In addition, in order to reach a full integration of QFD with MBSE, it would be important to consider the issues related to this specific application, i.e. the exploitation of modified QFD to support the selection of a suitable mission concept for transatmospheric vehicle. It is also worthwhile to consider that proper Graphical User Interfaces may be developed to ease the exploitation of such a design tool for non-practitioners.

Eventually, the authors will apply the methodology to different missions, demonstrating the flexibility of the envisaged tool chain as well as its wide field of applications.

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